



CENTER FOR ADVANCED AVIATION SYSTEM DEVELOPMENT (CAASD)

Radio-Frequency Interference to the Galileo E5b Signal in the United States

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Outline

- **GALILEO E5b signal and system**
 - Signal characteristics
 - Anticipated avionics performance
- **Systems operating at/near E5b center frequency, 1207.14 MHz**
 - 960 to 1215 MHz ARNS band
 - 1215 to 1390 MHz band
 - GNSS
- **Interference assessment method**
 - RTCA DO-292
- **Assessment results and summary**
 - Max degradation at 40,000 feet AMSL, 18,000 feet AMSL, 12,000 feet AGL



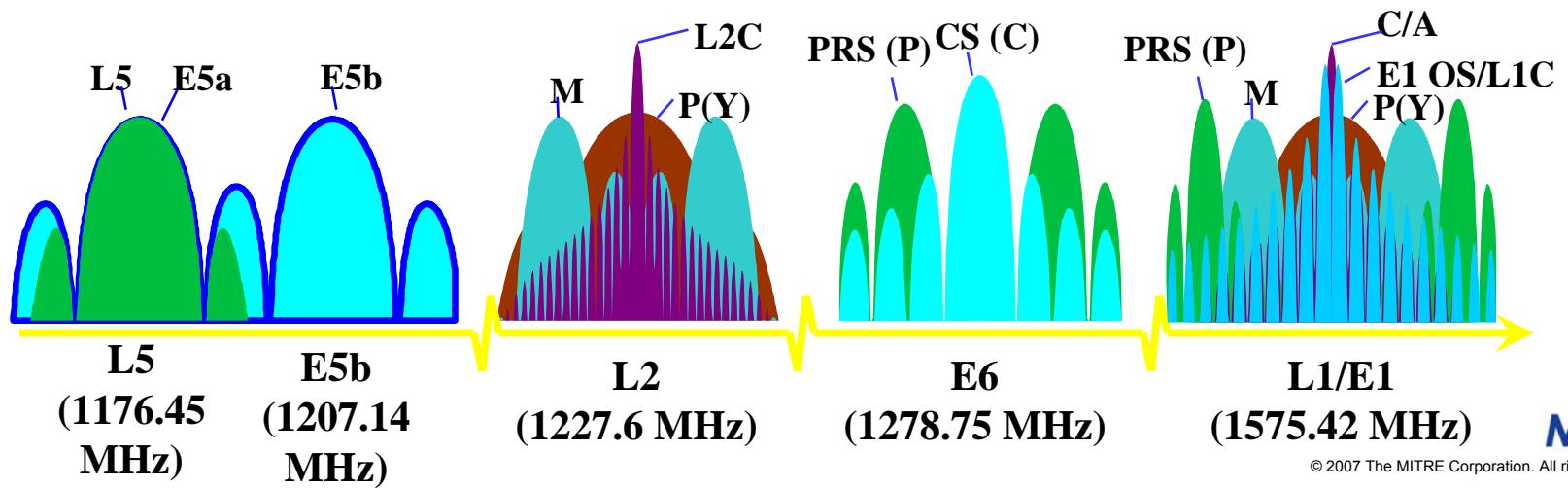
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GALILEO E5b Signal and System



GALILEO

- **GALILEO is a joint European Commission (EC)/European Space Agency (ESA) satellite navigation project**
 - Project began in 1999; will be Europe's contribution to the Global Navigation Satellite System (GNSS)
 - Galileo consists of 30 satellites, plus associated ground network, and is anticipated to be fully operational in the 2010-2012 timeframe
- **GALILEO satellites will broadcast six navigation signals**
 - Focus here is on E5b, centered at 1207.14 MHz
 - E5b is one of three signals that are intended for aviation use, along with E1 (1575.42 MHz) and E5a (1176.45 MHz)



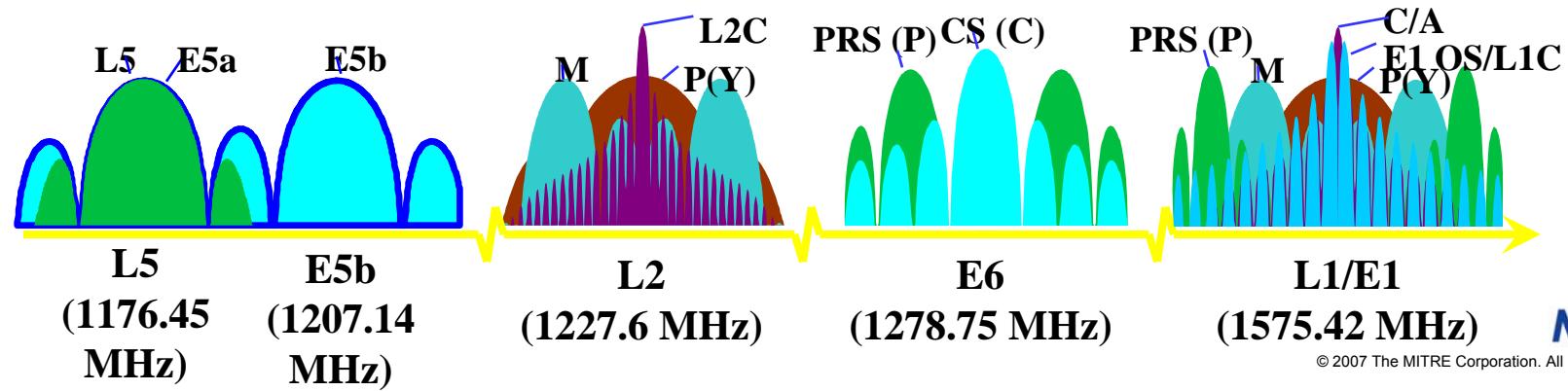
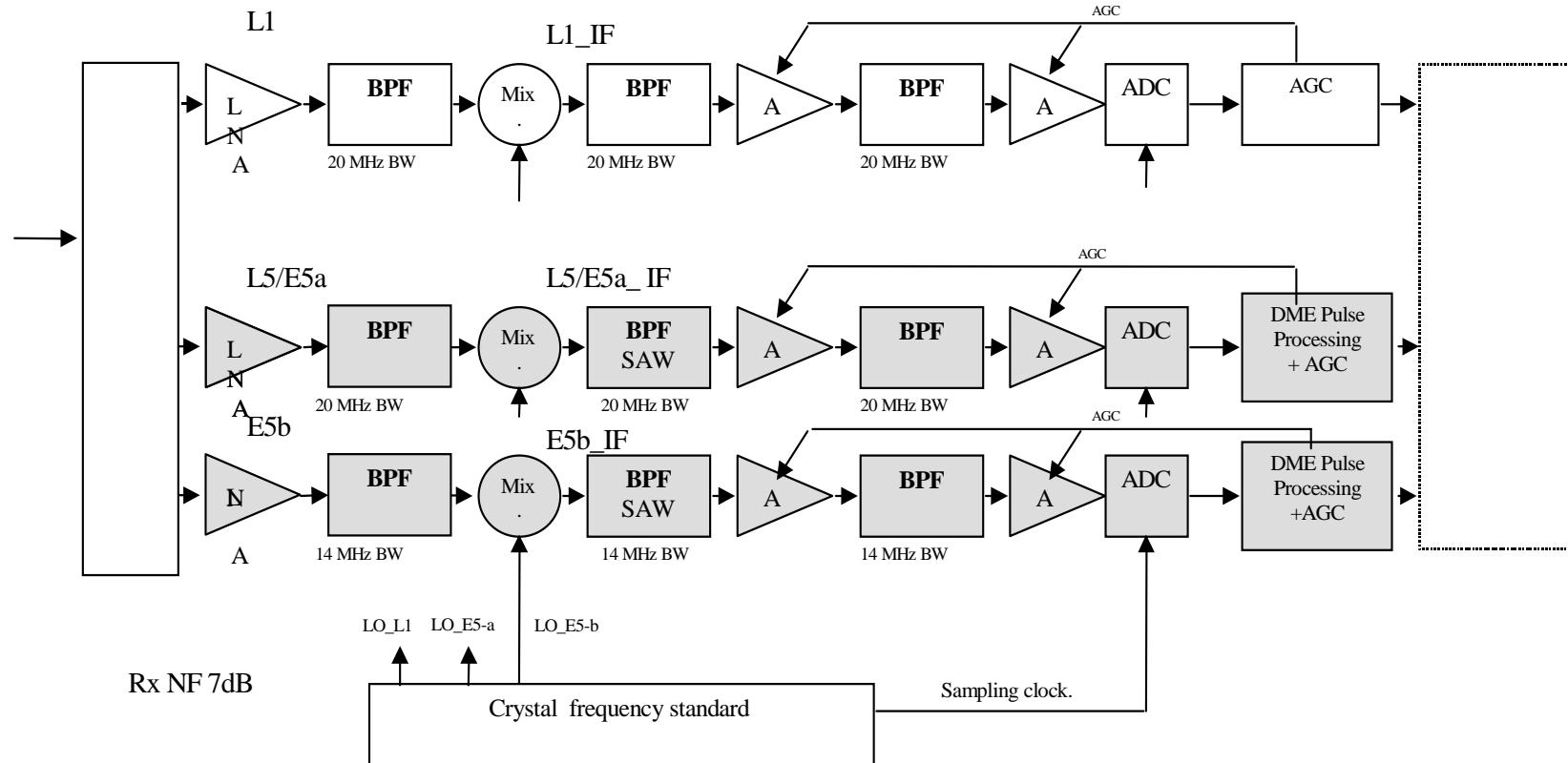


GALILEO E5b Signal

- **GALILEO E5a and E5b signals are generated coherently**
 - True carrier frequency is 1191.75 MHz
 - Modulation is referred to as ALTBOC
 - » Resemble two direct sequence spread spectrum signals using 10.23 MHz chipping rates and rectangular pulses - centered at 1176.45 MHz (E5a) and 1207.14 MHz (E5b)
- **Minimum received E5b power level is -155 dBW out of 0 dBic user antenna**
 - Half the power is devoted to a pilot component with only pseudorandom noise sequence (PRN) modulation
 - The other half is modulated by a PRN and 250 symbols/s (125 bps data with rate $\frac{1}{2}$ forward error correction)

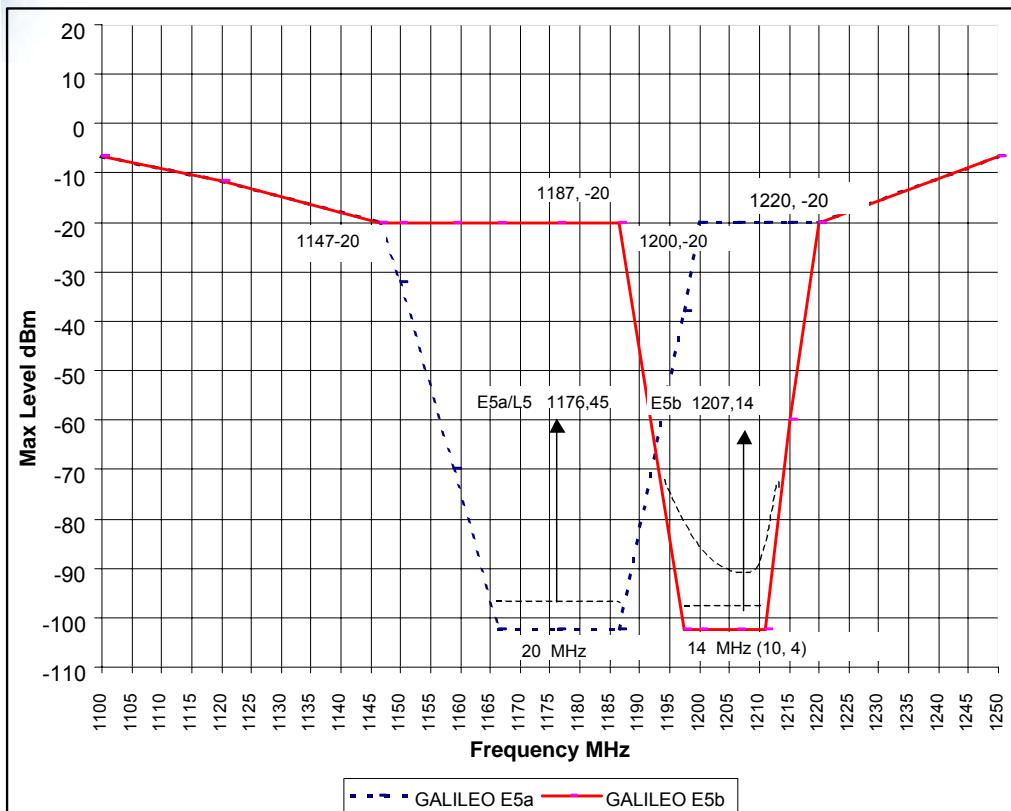


Galileo Receiver Front-End

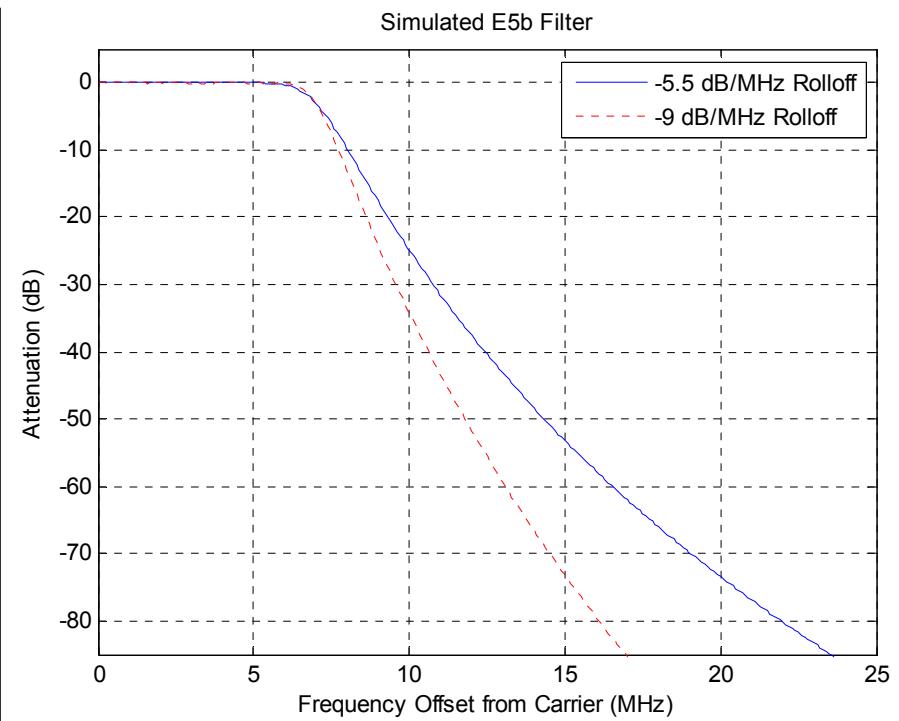




EUROCAE WG62 GALILEO Avionics Selectivity Requirements



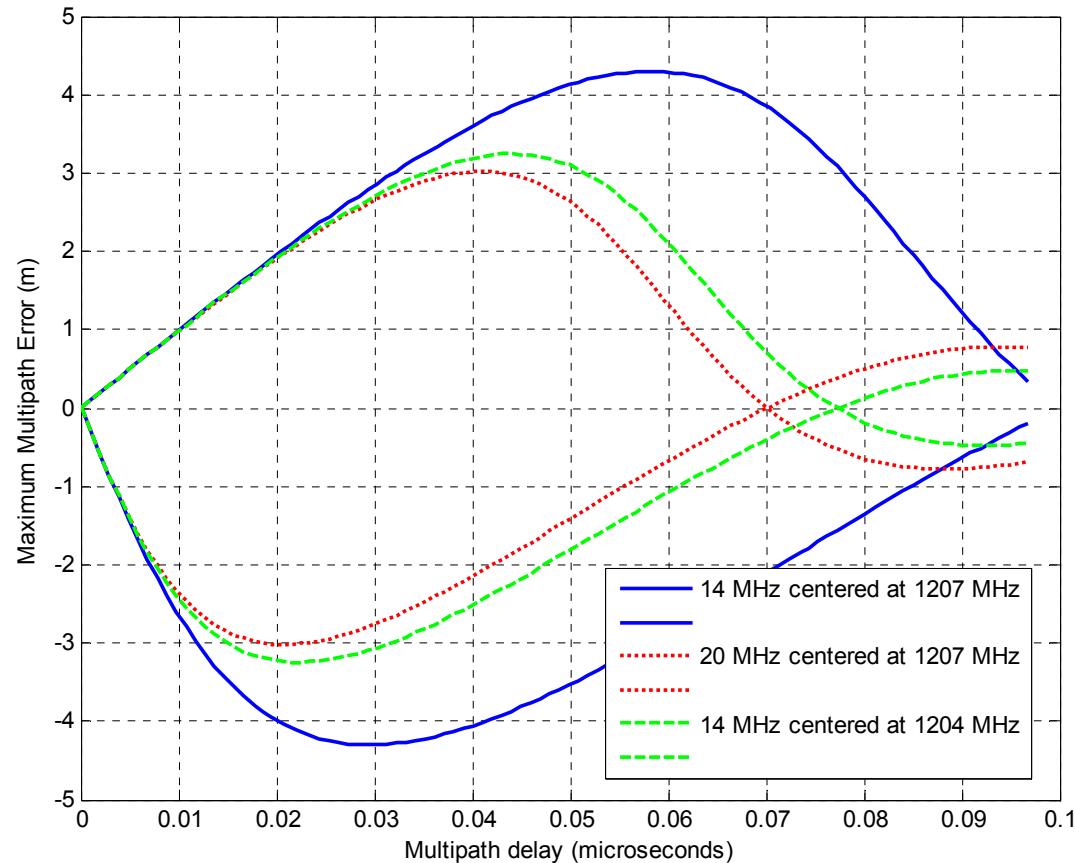
WG62 Selectivity Requirements



Digital Filter Used within
this Study



Impact of Receiver Selectivity on Multipath Performance



Maximum ranging error due to a strong specular reflection (amplitude of reflected signal voltage equal to one-half direct signal voltage; conventional early-late delay lock loop processing with 50 ns early-late spacing)

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Comments on EUROCAE E5b Selectivity Requirements

- **Practicality not assessed**
- **Required filtering yields ~14 MHz 3-dB bandwidth, whereas E5b signal has 20.46 MHz null-to-null bandwidth**
 - Filter is also centered at ~1204 MHz, whereas signal is centered at ~1207 MHz
 - Intent of tight selectivity mask is to attenuate signals from radars operating above 1215 MHz
- **Disadvantages of required filtering**
 - Results in signal-to-noise loss of ~1.2 dB vs. no filter or ~0.7 dB loss vs. 20 MHz filter
 - Results in slightly worse ranging precision in multipath than would be possible with wider (e.g., 20 MHz) filter



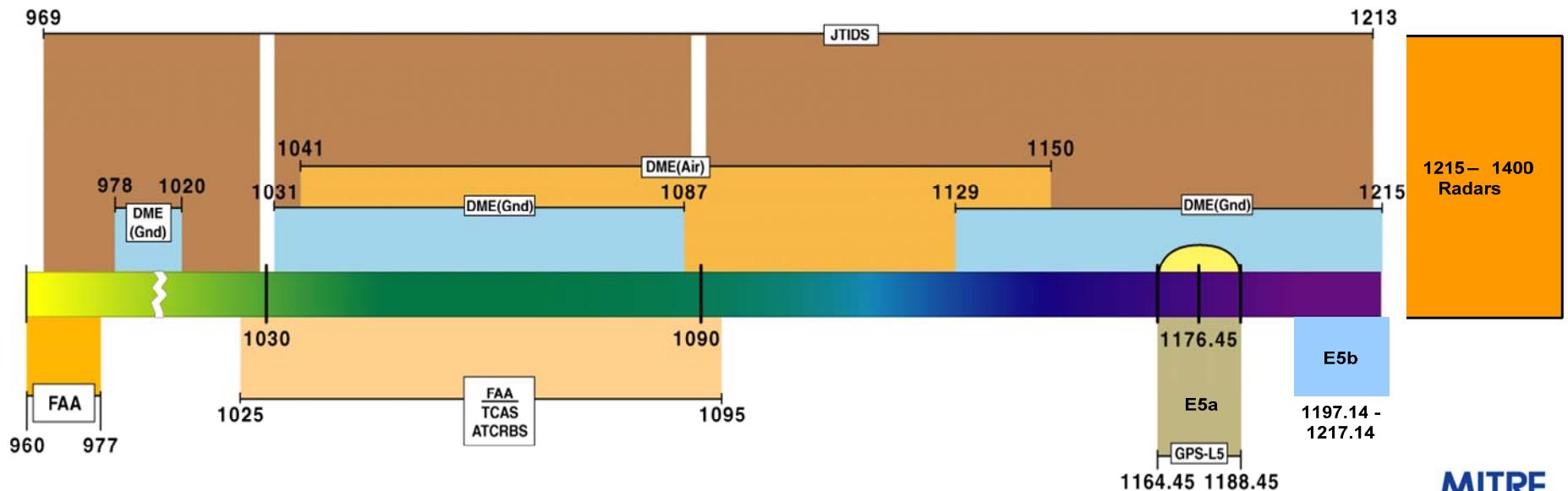
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Systems Operating at/near 1207.14 MHz



Systems Operating at/near 1207.14 MHz

- Radio frequency (RF) interference to Galileo E5b system can come from
 - RF radiation of aeronautical navigation systems in the 960 – 1215 MHz band
 - » DME/TACAN, JTIDS, ATC SSR, Mode-S, TCAS, UAT, etc.
 - RF radiation of the primary radar systems in the 1215 – 1390 MHz band
 - » ARSR-4,3,2,1, FPS-117, TPS 63, L-88, TPS-59(v3), FPS-66/67, and others
 - RF radiation from Global Navigation Satellite Systems (GNSS) – intra/inter
 - » GPS L5, Galileo E5a/ E5b, GLONASS L3, COMPASS, QZSS, SBAS





Some Modeled DME and Radars



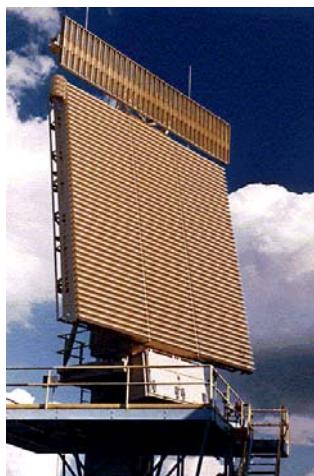
ARSR-1/2/3



TPS-59



L-88A



FPS-117



ARSR-4



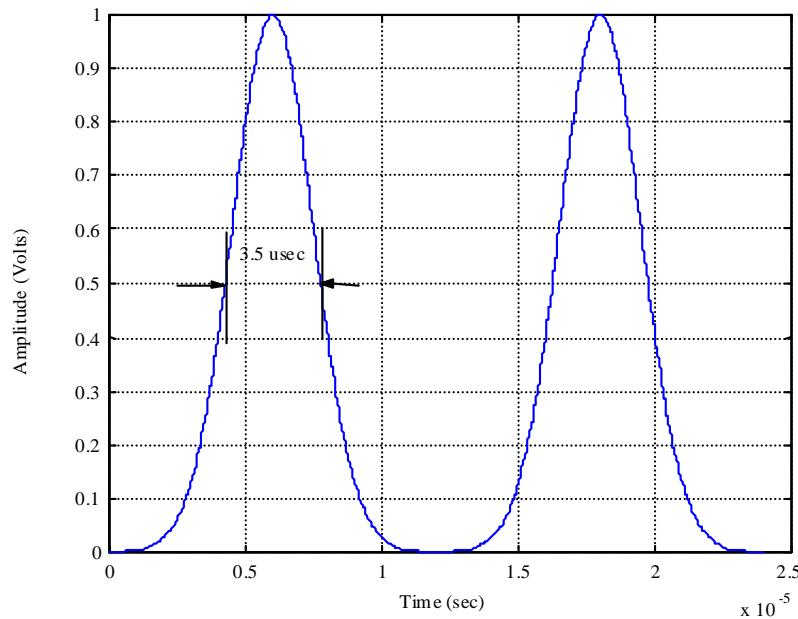
DME

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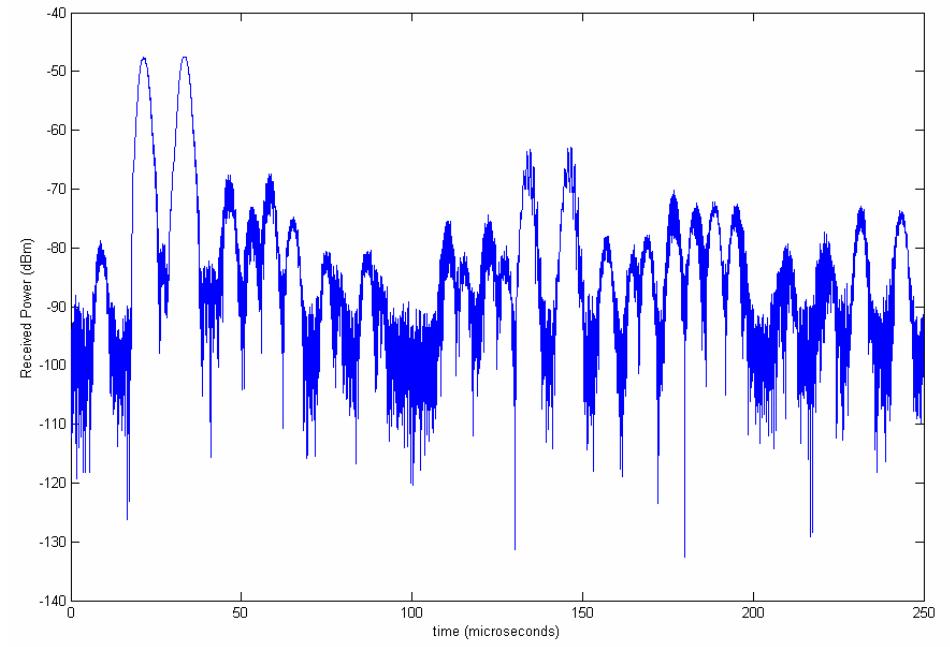
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Distance Measurement Equipment (DME)



DME pulse-pair signal



Aggregated DME signal

- DME, 2700 pulse-pairs per second
- TACAN, 3600 pulse-pairs per second

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ARSR-4 – Air Route Surveillance Radar



• System Characteristics

- Frequency, 1215 to 1390 MHz
- Elevation coverage, -7° to 30°
- Azimuth coverage, 360°

• Antenna

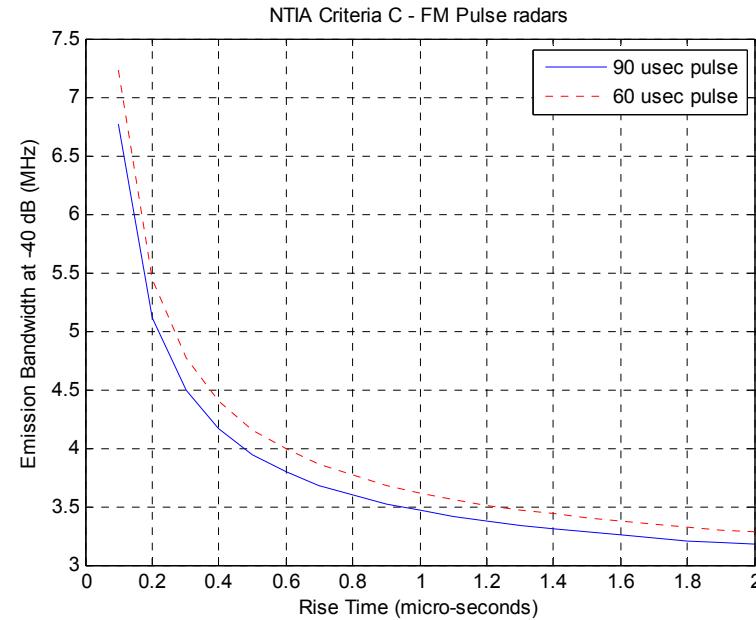
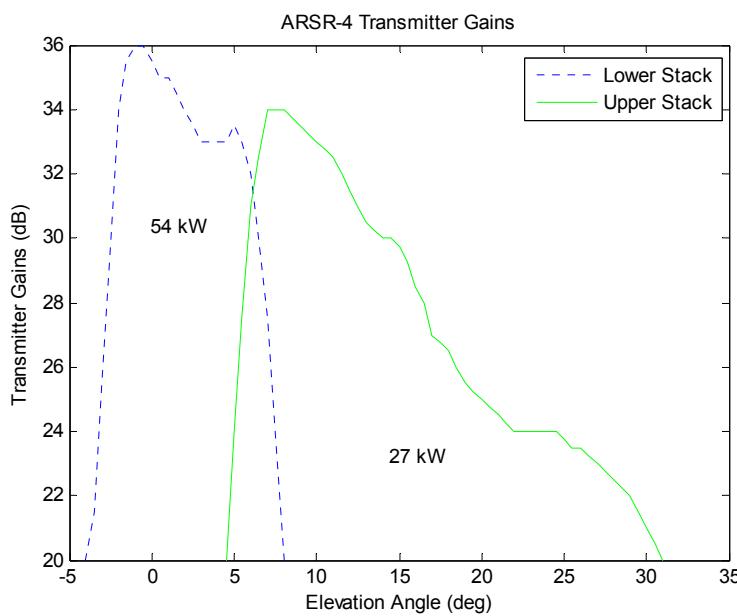
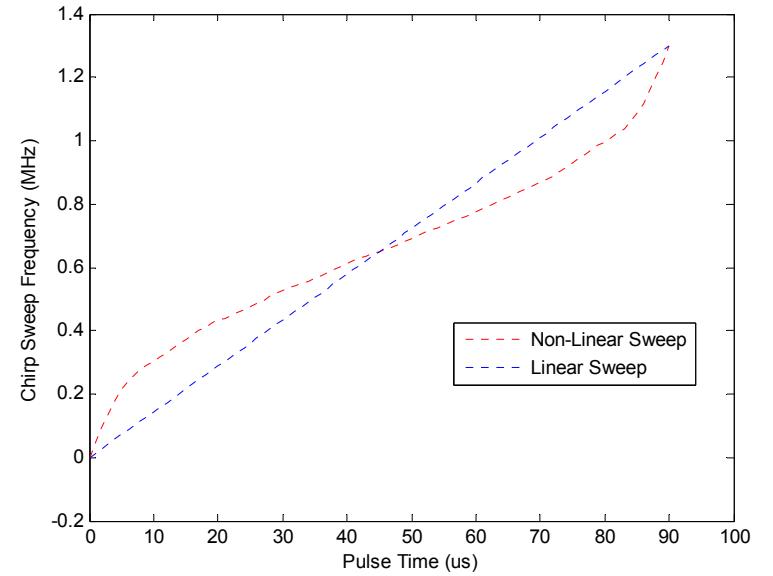
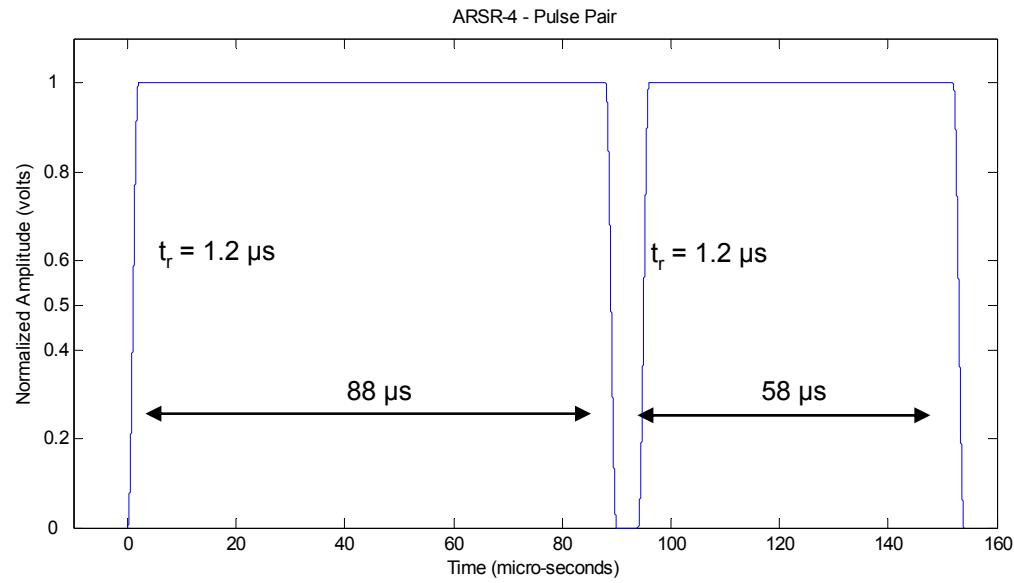
- Parabolic reflector with an array feed of 600 dual-polarized radiators; stack beam with 9 beams
- Transmit gain, 34.2 dB for low stack, 32.4 dB for high stack
- Sidelobes – Az, 35 dB down; Elev, 30 dB down
- Beamwidth, Az 1.4°, 3 dB
- Scan rate, 5 rpm
- Polarization, vertical or RHC

• Transmitter

- Solid-state modules
- Peak power, 89 kW (54kW on low stack, 27 kW on upper stack, 8kW on look-down)

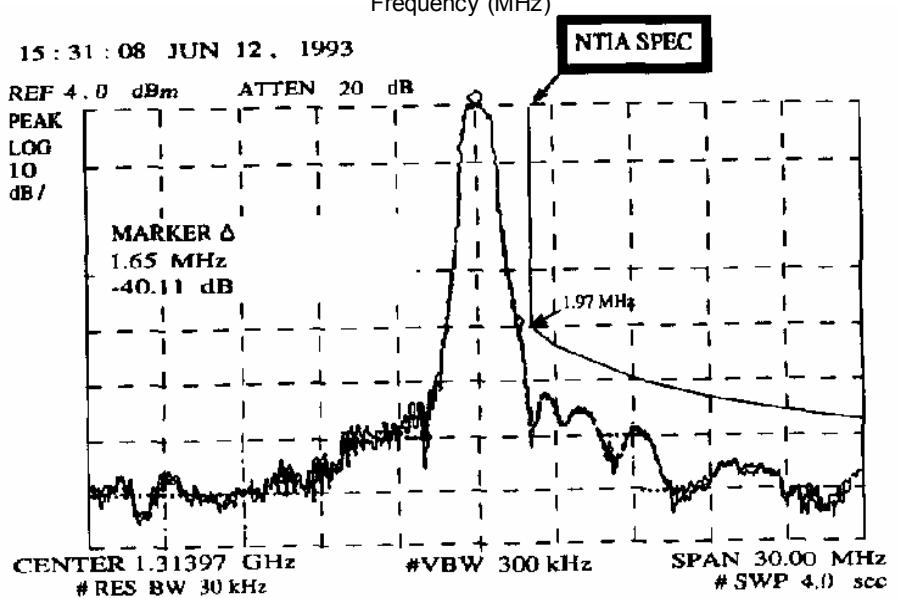
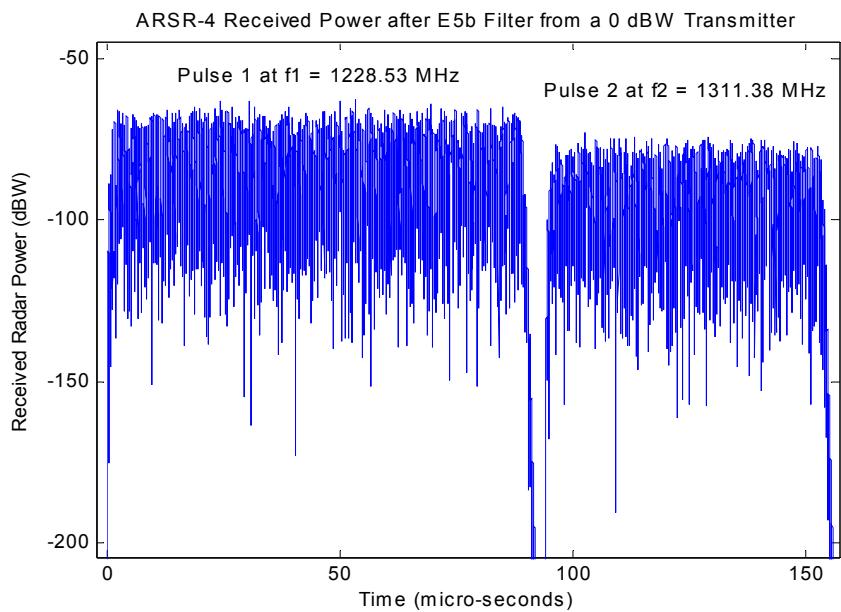
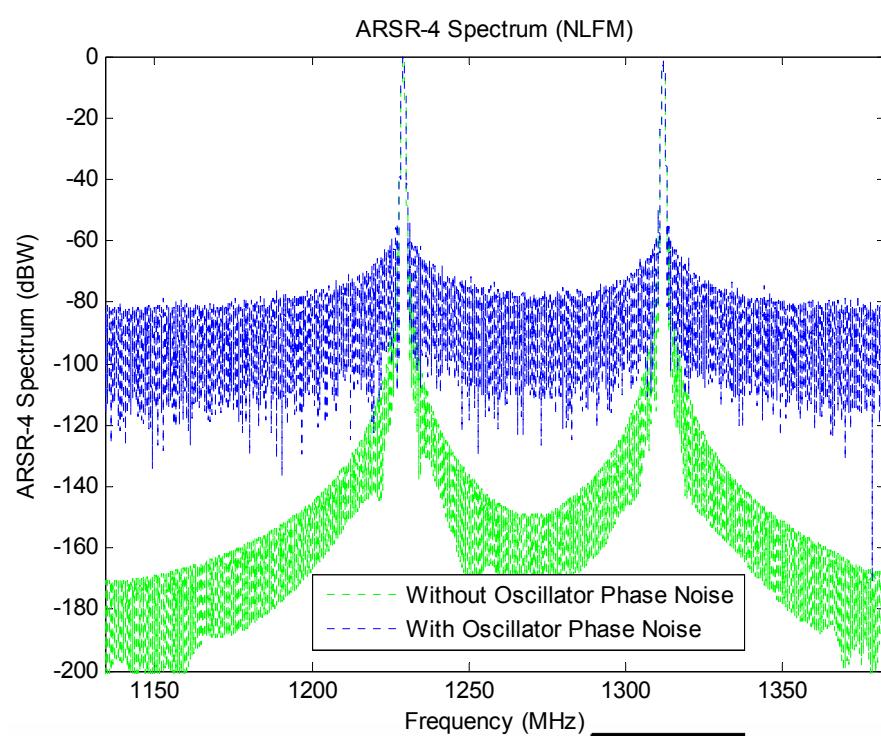
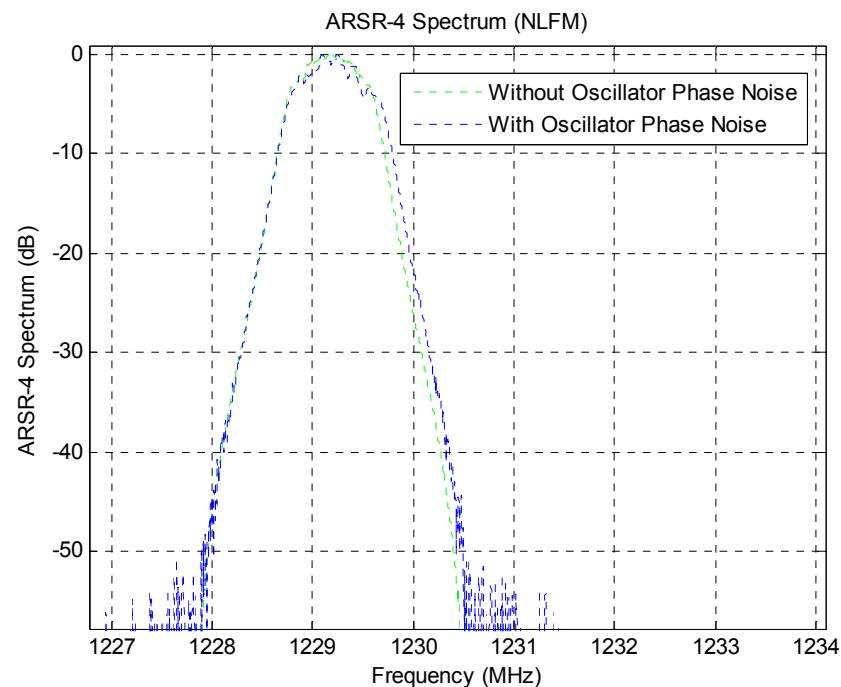
- Pulse width, 90 µs on F1; 60 µs on F2
 - » Rise/fall time, programmable from 0.5 to 2 µs
 - » Rise/fall pulse shape, cosine square
- PRF, variable from 164 to 316 pps
 - » Upper stack – 79 pps
 - » Lower stack – 237 pps
- Waveform, 2 subpulses spaced 83 MHz apart; each subpulse is digitally phase-coded to create nonlinear FM. Pulse compression is used on both pulses; Frequency diversity
 - » Sweep frequency = 1.3 MHz

ARSR-4 – Pulse Pair & Emission Mask



For the rising pulse shape (cosine square) of 2 us (0 to 100% amplitude), it take 60% of the total rise time, 1.2 μs , to rise from 10% to 90% amplitude.

ARSR-4 Emission Spectrum With Oscillator Noise





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Interference Assessment Method

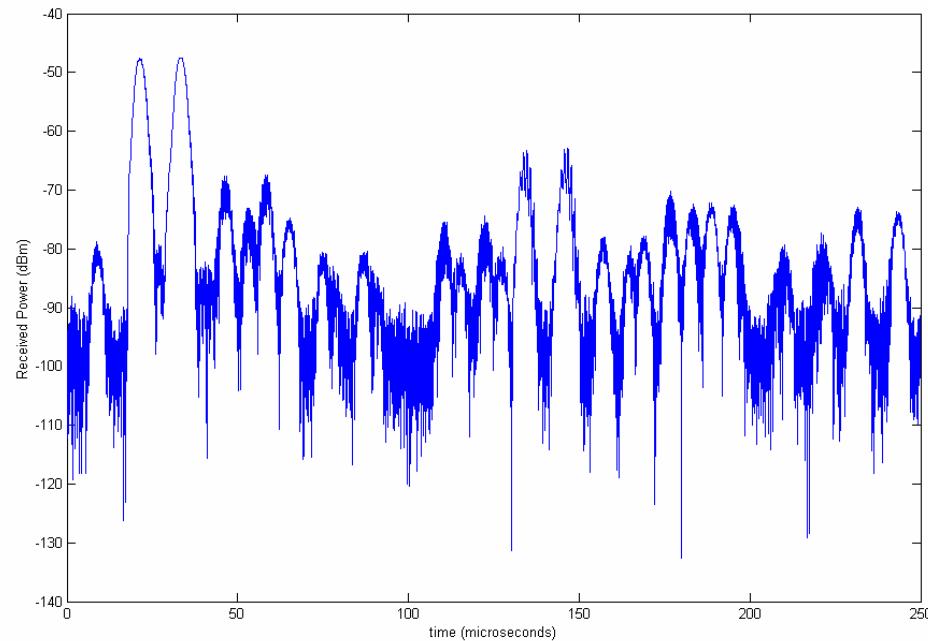


Interference Assessment Method

- **RTCA-DO 292**

$$C / N_{0,eff} = \left(\frac{C}{N_0} \right) \frac{(1 - PDC_B)}{\left(1 + \frac{I_{0,WB}}{N_0} + R_i \right)}$$

- $PDC_B = 1 - \prod_i (1 - PDC_{b,i})$, from multiple pulse emitter systems (DME/TACAN, JTIDS, radars, etc)





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Assessment Results and Summary

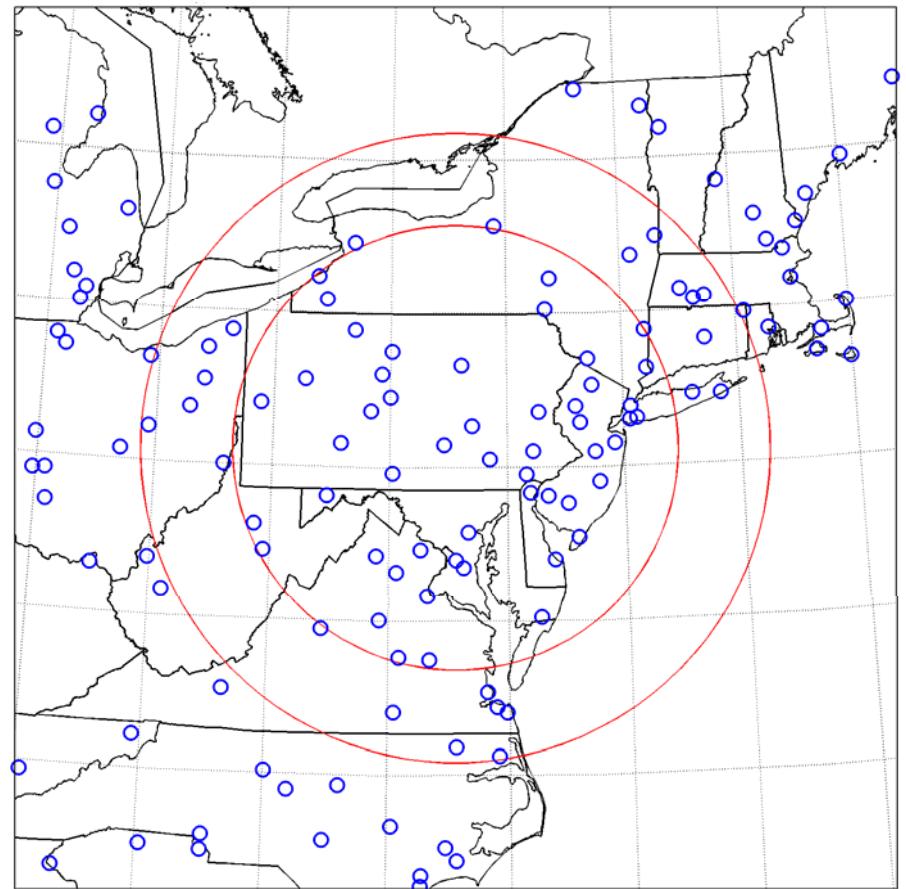
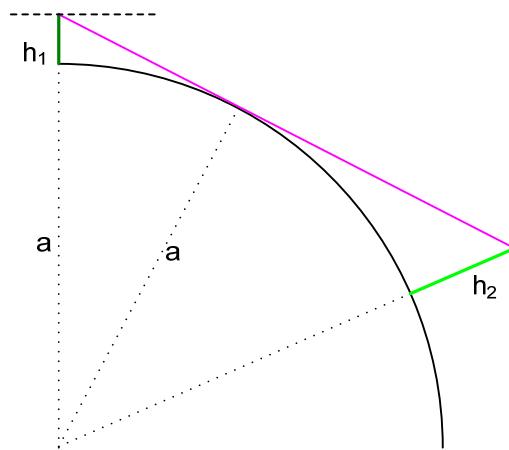
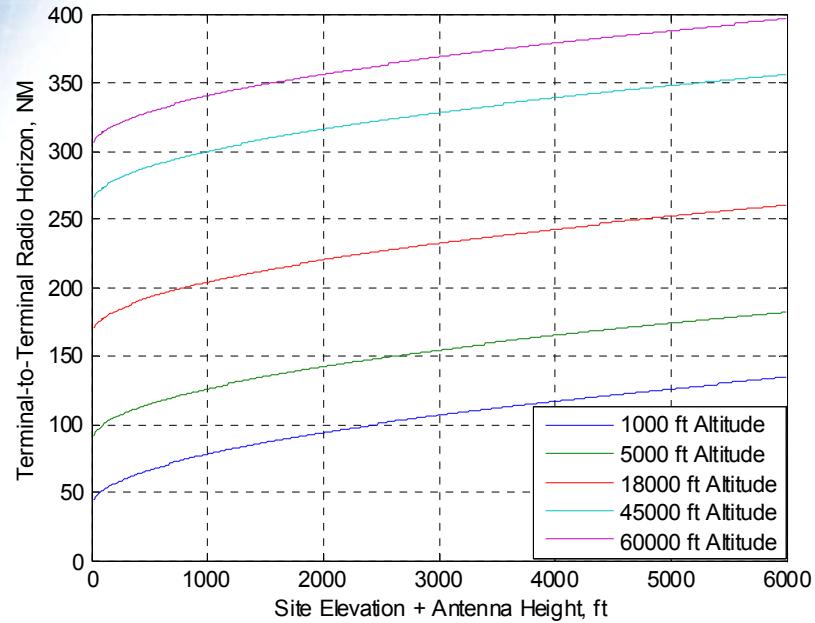


Databases and Assumptions

- **DME/TACAN Database in U.S.**
 - Locations (lat, lon), transmit powers, site elevations, antenna heights, transmit frequencies.
- **Radars Database extracted from U.S. GMF**
 - Locations (lat, lon), transmit powers, site elevations, antenna heights, transmit frequencies, hop frequencies.
- **U.S. Digital Terrain Data**
- **Victim aircraft Assumptions**
 - **Fan beam radar** - Victim aircraft are assumed to be hit by a maximum of two max power radar sites and by the radar sidelobes for other radar sites within the radio horizon.
 - **Pencil beam radar** - Victim aircraft are assumed to be hit by radar sidelobes from all radar sites within the radio horizon.
 - **4/3 spherical-earth radio propagation horizon**.



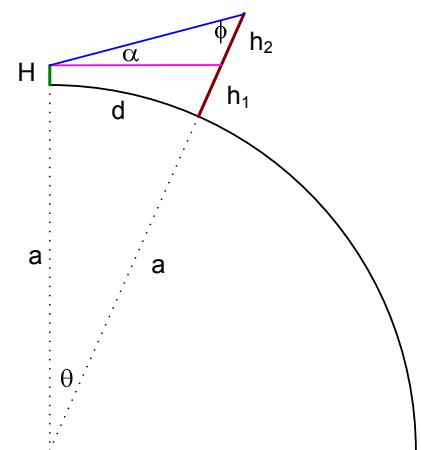
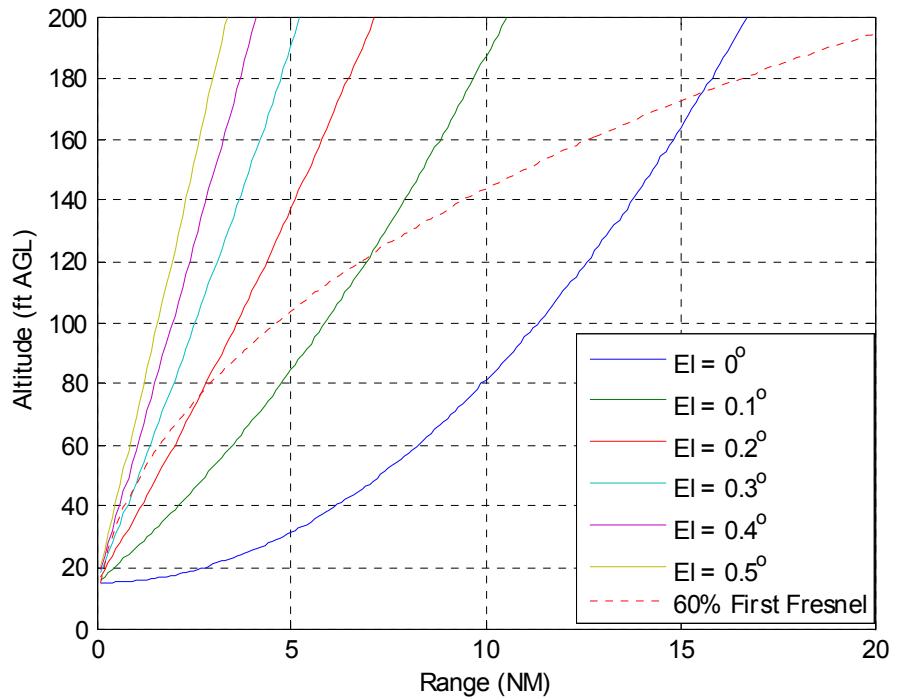
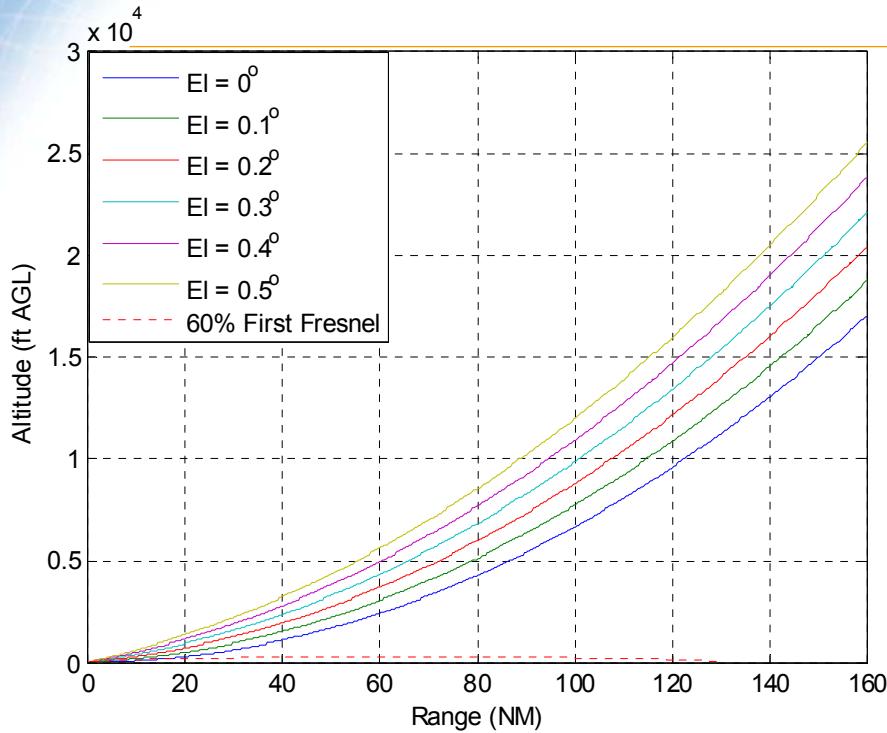
Radio Horizon



Radio Horizons at 20,000 and 40,000 ft



Fresnel Zone Clearance

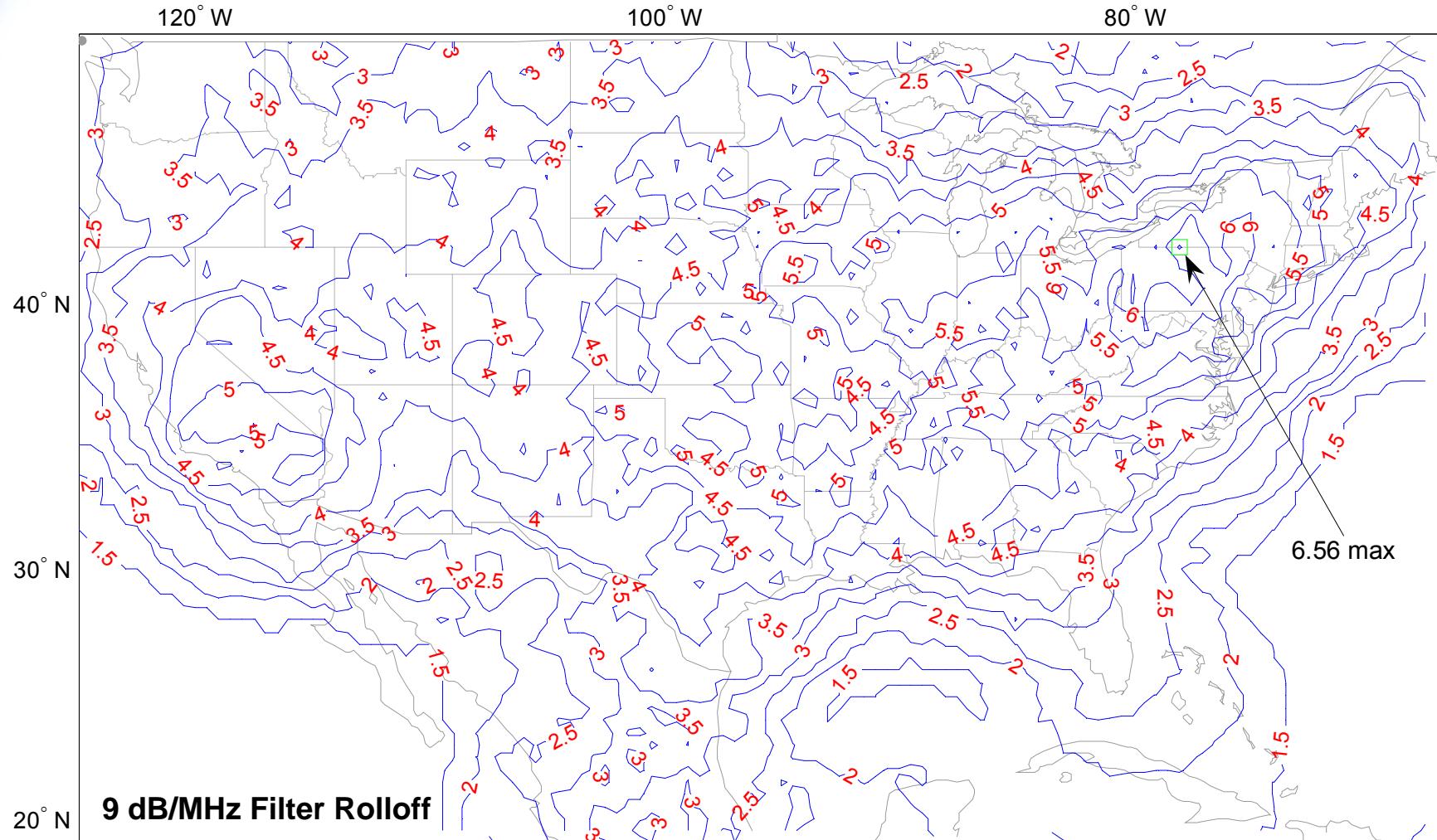


To clear 60% First Fresnel zone, an elevation angle of 0.4° is required



ALL Systems Interference at 40,000 Feet - E5b

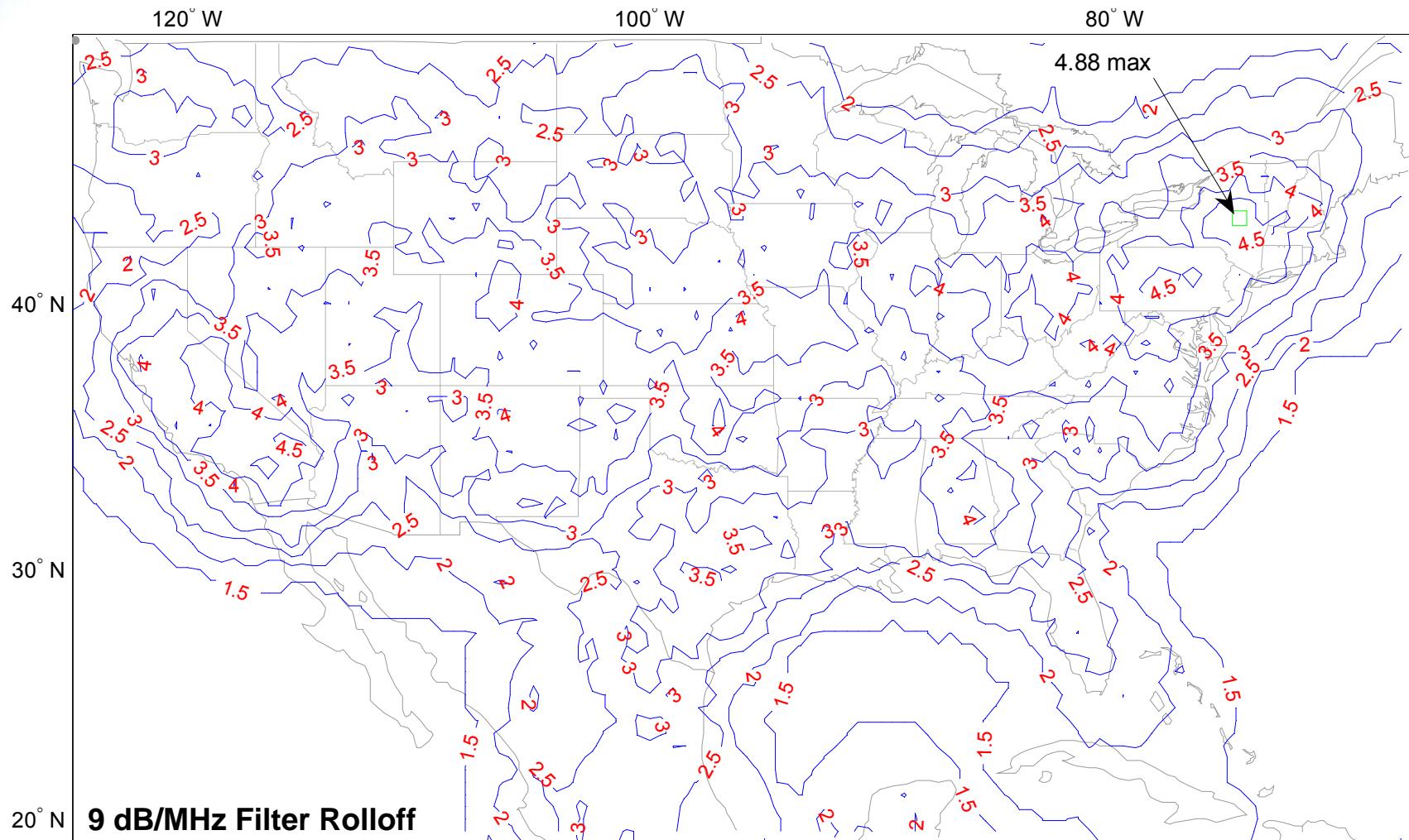
Max C/N₀ Degradation (dB)





ALL Systems Interference at 18,000 Feet - E5b

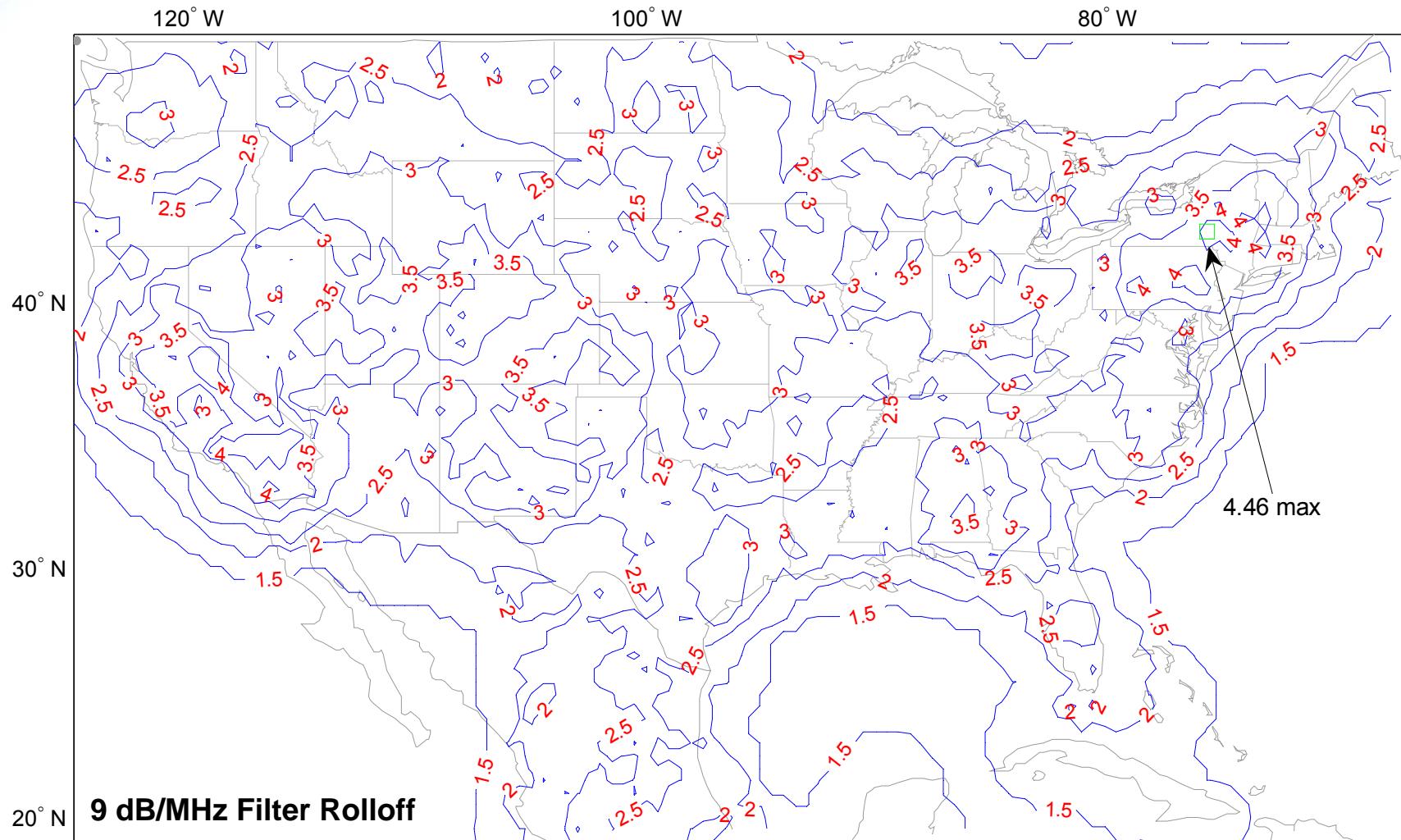
Max C/N₀ Degradation (dB)





ALL Systems Interference at 12,000 Feet - E5b

Max C/N₀ Degradation (dB)





E5b Maximum C/N₀ Degradation (dB) due to Interference

RF Interference Sources		Max C/N ₀ Degradation (dB)					
		40K Feet		18K Feet		12K Feet	
		- 9 dB/MHz	- 5.5 dB/MHz	- 9 dB/MHz	- 5.5 dB/MHz	- 9 dB/MHz	- 5.5 dB/MHz
Systems in 960 – 1215 MHz band	DME/TACAN only	5.45	5.91	3.6	3.72	3.2	3.48
	DME/TACAN + JTIDS + ATC Beacons + On-board systems	6.4	6.87	4.75	4.84	4.35	4.61
Systems in 1215 – 1400 MHz radar band	ARSR-4	0.13	0.13	0.43	0.43	0.55	0.55
	ARSR-3	0.06	0.06	0.04	0.04	0.04	0.05
	ARSR-1 and ARSR-2	0.03	0.03	0.03	0.03	0.03	0.03
	AN/TPS-59 (using 20 hop channels)	0.08	0.11	0.09	0.12	0.10	0.12
	L88A Aerostat	0.1	0.85	0.2	0.74	0.24	0.80
	AN/FPS-66 and AN/FPS-67	0.12	0.13	0.11	0.13	0.11	0.12
	AN/FPS-117 (Alaska only) (using 18 hop channels)	0.03	0.03	0.09	0.09		
	All above radars - CONUS	0.20	0.88	0.48	0.78	0.55	0.84
All Above Systems		6.56	6.94	4.88	5.07	4.46	4.70



Summary

- **E5b Min $C/N_0 = 40.5 - 2 = 38.5 \text{ dB-Hz}$ (assuming 2 dB implementation loss)**
- **Max degradation = 6.6 dB due to interference**
- **$C/N_{0, \text{EFF}} = 31.9 \text{ dB-Hz}$**
 - Required $C/N_0 = 31 \text{ dB-Hz}$, to ensure good acquisition and tracking performance.